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GIFFORD PINCHOT, Forester.

WOOD PRESERVATION IN THE UNITED STATES.

BY

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U. S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE,
Washington, D. C., August 31, 1909.

SIR: I have the honor to transmit herewith a manuscript entitled "Wood Preservation in the United States," by W. F. Sherfesee, in charge of Wood Preservation, and to recommend its publication as Bulletin 78 of the Forest Service. The four plates and three diagrams are necessary for its proper illustration.

Very respectfully,

GIFFORD PINCHOT,
Forester.

Hon. WILLET M. HAYS,
Acting Secretary of Agriculture.

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WOOD PRESERVATION IN THE UNITED STATES.

THE AIM.

Though wood is perhaps the most widely used material, it has one serious drawback, for if exposed to the weather or placed in contact with the soil it will last but a comparatively few years. No substance, of course, will last forever; even stone and steel will crumble and corrode with time. But the life of wood in its natural state, even at the longest, falls far short of that of other structural materials. Yet wood is made to serve so many purposes, and is so peculiarly adapted to certain uses for which no real substitute has been found, that the problem of how best to prolong its life in service is of the first importance.

One very great advantage which wood has over other materials is its comparative cheapness. This advantage, however, has been growing steadily less as the cost of wood has mounted higher and higher. To timber a mine, to build a fence, or to lay a railway track, with the woods best suited to each, costs, in many cases, twice as much as it did fifteen years ago. Naturally, the tendency has been to discontinue the use of the better woods, which have steadily grown scarcer and more expensive, and to substitute inferior ones, with only their cheapness and availability to recommend them. Thus, with the high cost and scarcity of the better woods, and with the exceedingly short life of the cheaper ones, the user faces a serious condition. To meet it, if wood is to remain a cheap material, its life must be prolonged by the use of chemical preservatives.

Wood preservation, by prolonging the life of timber, does more, however, than to justify the cost of expensive woods or permit the use of cheaper ones. It gives the user a much wider field for the selection of his material than he otherwise would have. Woods which were once considered worthless can be treated and made to last practically as long as any others.

Already the preservative treatment of timber is widespread, and each year sees it applied more extensively. It is the purpose of this publication to give briefly but completely the general principles of wood preservation and its status in the United States to-day.

WHAT DECAY IS.

The decay of wood is not an inorganic process, like the rusting of iron or the crumbling of stone, but is due to the activities of low forms of plant life called bacteria and fungi. Bacteria are among the simplest of all forms of life, often consisting of but a single cell, microscopic in size. Sometimes several such cells may be attached to each other, and so form a thread or filament. Usually they are colorless, and multiply by the division of the parent cell into other cells which, in turn, divide again.

Fungi, although much more complicated than bacteria, are also low in the scale of creation when compared with familiar flowering plants and shrubs. They consist merely of tiny threads or hyphæ, which are collectively known as the mycelium. In many of the higher forms of fungi the threads grow together to form compact masses of tissue. Familiar examples of these forms are the toadstools, which grow on damp, rotting logs, and the "punks," or "brackets," on the trunks of trees in the forest. (Pl. I, fig. 1.)

The causes of decay in wood, however, are not these fruiting bodies themselves. Spores, very primitive substitutes for seed, which are borne in the countless compartments into which the under surfaces of the fruiting bodies are sometimes divided, are produced in infinite number, and are so fine that they can be distinguished only by the microscope. When seen in bulk they appear as the finest dust. Like dust, they are carried by the wind and strike all portions of the surrounding objects. Few species of fungi successfully attack healthy living trees, and only a comparatively small number can attack and destroy wood. Yet the spores of some find a lodging in dead portions of a tree or in cut timber, and if the wood is moist and in the right condition for the spore to grow it germinates and sends out a thin, film-like white thread which, by repeated branching, penetrates the entire structure of the wood. These are the real agents of decay.

This is not the only way that a fungus can enter a sound stick of timber; for if a good stick is lying close to a rotting one, the mycelium may grow over or through the moist ground and so reach the sound stick, which it immediately attacks. Sometimes, too, when a tree is cut it already has a fungus growing in its wood. If the fungus happens to be a true parasite—that is, if it can grow only in living tissues—it will die when the tree is felled; but if it has been accustomed to growing in the heartwood of the tree, which is practically dead, it may continue to live and develop even after the tree has been sawed into timber.

Wood is composed of minute cells. The chief material of the cell-walls is a substance called cellulose, and around this there are in-

FIG. 1.—SECTION OF SHORTLEAF PINE, SHOWING HOW A FUNGUS (TRAMETES PINI) ENTERED THROUGH AN OLD BURN, DESTROYED THE HEARTWOOD OF THE INTERIOR, AND GREW OUT TO FORM A FRUITING BODY OR "BRACKET."

FIG. 2.—CONTRAST BETWEEN TREATED AND UNTREATED PINE MINE PROPS AFTER ONE YEAR'S SERVICE IN A COLLIERY IN THE ANTHRACITE REGIONS OF PENNSYLVANIA.

[The third prop from the left was treated with creosote; the fourth prop, untreated, was set at the same time.]

crusted many different organic substances known collectively as lignin. Most of the wood-destroying fungi attack only the lignin; others attack the cellulose alone, while a third class destroy all parts of the wood structure. The lignin and the cellulose are dissolved by certain substances secreted in the fungi, and thus serve as food for the fungus growth. In this way the fungi can develop until they extend throughout every portion of the timber. After a time the amount of fiber changed into food and assimilated by the fungus causes the wood to become discolored. Discoloration may also be produced by pigments in the fungus or secreted by it. Finally so much of the wood fiber is eaten away or changed in composition that its strength is greatly diminished, the texture becomes brittle and disconnected, and the wood is said to be "rotten."

But food is not the only thing that a fungus requires for its growth and development. It must also have heat, air, and moisture. If any one of these is lacking the fungus can not develop. The necessary heat is supplied by almost every climate, and it is only in rare cases, as under water or deep under the surface of the ground, that air can be excluded from the timber. Of the four requirements, therefore, two are beyond control. It is only by depriving the fungi of food or moisture that the destruction they cause can be prevented.

HOW DECAY CAN BE RETARDED.

BY SEASONING.

The simplest way to prolong the life of timber exposed to the attack of wood-destroying fungi is to reduce the moisture content of the wood. The amount of water in green timber varies according to the part of the tree from which the wood is cut. The outer layers of the trunk are composed of sapwood, the cells of which contain large amounts of organic substances which serve excellently as food for the fungi. Moreover, sapwood always contains a large amount of water. It is the portion of the tree, therefore, most susceptible to attacks from fungi. Heartwood, which can usually be distinguished from sapwood by its darker or more reddish color, contains, on the other hand, much less moisture. It is therefore more durable than sapwood. But because its pores are stopped up by gums and resins it dries out much less rapidly than the more porous sapwood. In almost every case as much care should be taken thoroughly to dry out the heartwood as in the case of the moister sapwood.

By piling the timber so as to permit free access of air all around it the moisture content of timbers of certain sizes can be reduced to about 15 or 18 per cent. Of course the climate has a great influence on the rate at which the wood dries out and the total amount of moisture it loses.

The moisture content of air-dry wood can be still further reduced by kiln-drying; and this is employed to a considerable extent, but usually for other purposes than increasing the durability of the wood. Moreover, either air-dry or kiln-dry wood has the power to reabsorb moisture when exposed to the atmosphere in damp situations, and so the benefits of drying, as far as durability is concerned, are only moderate.

The strength of partially seasoned timber, other things being equal, increases as the amount of moisture it contains decreases. Thoroughly seasoned timber of small sizes is sometimes three or even four times as strong as the same timber when green. Moreover, during the process of drying out, important but little understood changes take place in the organic contents of the wood cells, by which the wood is not only rendered less attractive to fungi, but is made more permeable and so better prepared for preservative treatment.

An exterior coating secured by dipping a post in a thin solution of cement or other material that will harden on the post is not an effective protection, because in shrinking or swelling the wood forms cracks through which decay enters.

BY CHEMICAL IMPREGNATION

By far the best method of checking the growth of fungi, however, is to poison their food supply. This can be done by injecting poisonous substances into the timber, and so changing the organic matter from foods suitable for fungi into powerful fungicides. It is a mistake to suppose that the germs of decay are inherent in the wood and only need an opportunity for development to bring about its destruction. Several processes for the preservation of wood have been founded on the false assumption that it is necessary to destroy the "germs" in the interior of the timber. The impression doubtless arose from the fact that, after a stick of timber begins to rot, it is impossible to tell just where the fungus spores germinated and gained entrance into the timber. Moreover, the fact that the heartwood of the tree may have become infected before felling, or that the interior of a stick of timber may have reached an advanced stage of decay before there are any external evidences of the fungi—such as fruiting bodies, or films of mycelium—tends to convince the casual observer that decay starts from the interior. Yet the wood-destroying agencies start from the outside. If the interior is sound, this explains the efficacy of certain paints which merely form a superficial coating over the surface of the timber, but which are poisonous enough to prevent the spores from germinating, or the hyphæ of most forms of wood-destroying fungi from penetrating into the unprotected wood in the interior. The ancients were in the habit of painting their statues with oily and bituminous preparations

to preserve them from decay. The great wooden statue of Diana at Ephesus, which was supposed to have descended miraculously from heaven, was protected from earthly decay by oil of nard. Pettigrew extracted the preservative fluids from the heart of an Egyptian mummy that had resisted decay for over three thousand years, and found that decomposition immediately set in. This showed that it was the presence of the antiseptics which prevented decay, and not a chemical change of the tissues.

PRESERVATIVES AND PROCESSES IN THE UNITED STATES.

Of the many antiseptics which have been proposed for the preservation of timber only four have been largely used with success in the United States. These are creosote (dead oil of coal tar), zinc

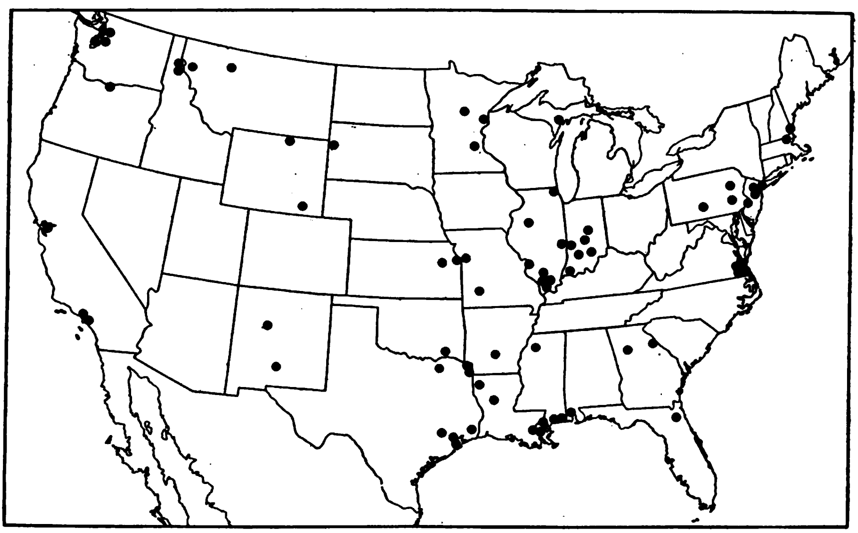

FIG. 1.—Map showing the location of the timber-preserving plants in the United States.

chlorid, corrosive sublimate (bichlorid of mercury), and copper sulphate. At the present time copper sulphate has fallen into almost total disuse, and corrosive sublimate is restricted to two plants in New England. The use of corrosive sublimate is the so-called "Kyanizing" process which is so frequently referred to in all the literature of wood preservation. In general, the process consists in steeping the timber in a dilute solution of corrosive sublimate long enough to insure thorough penetration.

THE CREOSOTES AND ZINC CHLORID.

In the United States creosote and zinc chlorid are the only preservatives in common use. There are many patented preservatives known by various names, but most of them have for their base one

or the other of these two preservatives. Creosote is a by-product of coal tar, which is produced at most plants for the manufacture of illuminating gas and at by-product coke-oven plants. Coal is heated in a retort from which air is excluded. The gases produced are driven off and collected, the lighter ones first and progressively heavier ones as the heat of the distillation increases. As the accompanying diagram (fig. 2) shows, there are two other products of this distillation—coal tar and coke.

A second distillation is made of the coal tar, and this also results in three products: (1) Oils with a specific gravity less than 1, of which crude carbolic acid is a typical constituent; (2) oils heavier than water, known as dead oils of coal tar, coal-tar creosote, or most frequently, simply as creosote. The third product of the distillation, which remains in the retort as a residue, is pitch. Creosote is not a

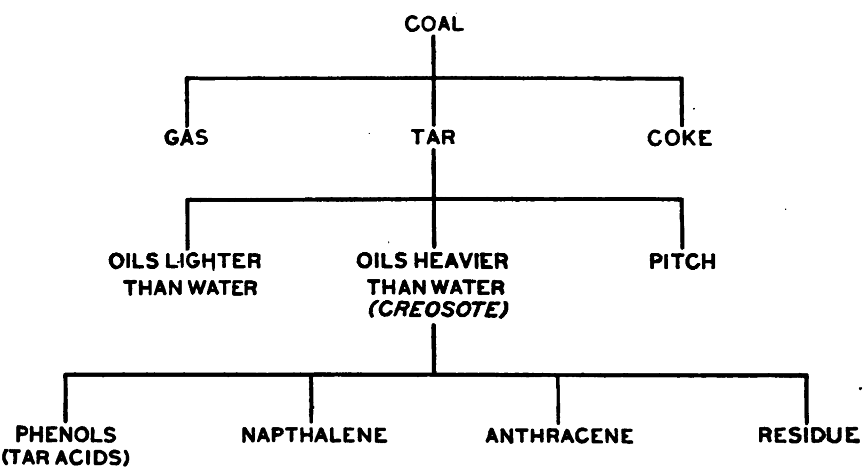

FIG. 2.—Diagram showing the derivation and composition of creosote.

simple substance like zinc chlorid. On the contrary, it contains a large number of substances of great chemical complexity, of which the so-called tar acids or phenols, naphthalene, and anthracene are the most important in wood preservation. Although by "creosote" is generally meant the dead oil of coal tar, the name is also applied, alone or with a modifying adjective, to preservatives derived from other substances. Thus, wood tar, when distilled like coal tar, gives "wood creosote," which also possesses strong antiseptic properties and is used to preserve timber.

Petroleum-tar creosote (also known as water-gas-tar oil, water-gas-tar creosote, and oil-tar creosote) is produced by a different process. It is a by-product of the manufacture of the water gas so largely used for illumination. Steam is passed over white-hot coke in a closed cylinder, and thus broken up into hydrogen and

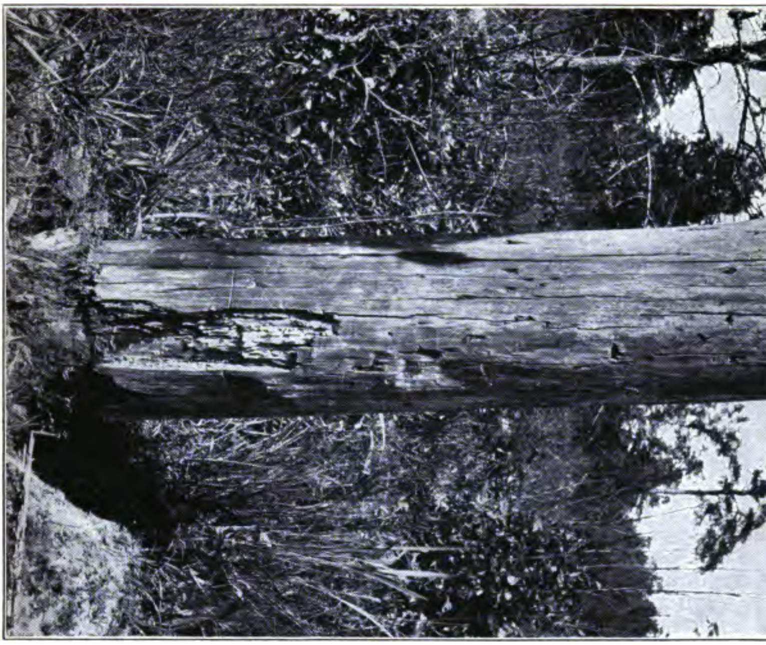

FIG. 1.—UNTREATED POLE OF SOUTHERN WHITE CEDAR (CHAMÆCYPARIS THYOIDES) AFTER FOUR YEARS' SERVICE.

FIG. 2.—CREOSOTED LOBLOLLY PINE POLE AFTER EIGHTEEN YEARS' SERVICE. NO SIGN OF DECAY.

oxygen. These are passed into another highly heated cylinder, called the "carburetter," into which is also injected a finely divided stream of crude petroleum. The resulting gas, after being cleansed and purified, is ready to be pumped into the mains. The tar is collected and distilled, and thus the petroleum-tar creosote is obtained. Sometimes the tar itself is used as an adulterant of coal-tar creosote, or even alone as a wood preservative. Petroleum-tar creosote is already used in large quantities; but most of it is sold, not under its own name, but as an adulterant of coal-tar creosote. This is unfortunate, for although its value as a wood preservative is not yet fixed, in all probability it can win a place for itself on its own merits. If it does it will do much to relieve the excessive demand for coal-tar creosote, which already far exceeds the domestic supply.[a] It contains some of the most important constituents of coal-tar creosote, as well as oils of the paraffin series. Its analysis by fractional distillation is sometimes identical with that of the coal-tar product, and it is probable that, after injection into timber, it would show no more rapid volatilization.

The deficient supply of creosote in the United States has resulted in the use of crude oil for the preservation of timber. Although its antiseptic properties are low, it serves to exclude water from the timber and so to prevent decay. The timber is saturated with the oil by one of the "full-cell" processes described later. Only those oils are used which have a heavy asphaltum base, such as are found in Mexico and in certain portions of California. Most of the other oils produced in the United States have a paraffin base, and at present are not considered adapted for use in wood preservation. Efforts are being made, however, to overcome this difficulty. Crude oil has been extensively used for a number of years by one of the largest railroad systems of the West, and the results, so far, have been distinctly satisfactory.

Zinc chlorid is obtained by dissolving metallic zinc in hydrochloric acid. This is diluted by water before it is used for wood preservation.

Both creosote and zinc chlorid are excellent antiseptics. Creosote's principal point of superiority, however, lies in its insolubility in water. Once it is injected into timber it will not wash out, no matter how wet may be the situation in which the treated timber is placed. Zinc chlorid is much cheaper than creosote, and since it is shipped in the form of a solid, the freight charges are considerably

[a] In 1908 more than 56,000,000 gallons of creosote were used in the wood-preserving plants of the United States. Of this amount, 69 per cent was imported (principally from England and Germany, and a small amount from Canada) and only 31 per cent of the total supply was produced in this country. Nearly 19,000,000 pounds of zinc chlorid were used, all of which was manufactured in the United States.

less. But zinc chlorid is soluble in water, is, in fact, injected into the timber in water solution, and when timber treated with it is exposed to moisture the leaching out of the salt is only a question of time. Hence, zinc chlorid is most commonly used in comparatively dry situations. Creosote, on the other hand, is used where the timber will be subjected to moisture. Moreover, creosote is one of the very few preservatives in use which offers effective protection against the marine borers, which work such havoc among the wharves of the Atlantic, Gulf, and Pacific coasts. Since it is insoluble in water it can not wash out of the piles, if properly injected, and since it is more than a mere external coating, there is no danger of its being broken off by floating débris.[a] (See Pl. IV.)

The processes by which the preservatives are injected into the timber may be divided into two general classes, the "pressure processes" and the "nonpressure processes." The latter term is somewhat misleading, for it implies that no pressure at all is employed. This is inaccurate, for with the exception of "kyanizing," "dipping," and the "brush treatments," to be described later, pressure in some form is used in all wood-preserving processes. The essential difference between the pressure and nonpressure processes is that in the former the pressure is applied by force pumps, compressed air, or similar means, while in the latter atmospheric pressure alone is relied on.

Each of these classes may be further subdivided into the "full-cell" and "empty-cell" processes. Some processes, both "pressure" and "nonpressure," force the preservative into the wood so as to fill the cells and intercellular spaces; hence they are known as the "full-cell" processes, and the result is a "full-cell treatment." The aim of the other processes is merely to leave only a film of the preservative around the cell walls, and hence either smaller amounts of the preservative are forced into the wood or else the superfluous oil is extracted after the penetration has been secured. Sometimes a combination of these two methods is employed. Needless to say, the "empty-cell" treatment is the cheapest, other things being equal; and though this is sometimes not its only advantage, it has been the chief factor in extending its use.

THE PRESSURE PROCESSES.

Until very recently the pressure processes were used in the United States practically to the exclusion of all others. In England and on the Continent they are still almost universally employed.

[a] A more detailed discussion of this may be found in Forest Service Circular 128, Preservation of Piling Against Marine Wood Borers.

THE BETHELL PROCESS AND BURNETTIZING.

The two most widely used processes are the "Bethell" and "Burnettizing." They differ only in the preservative. In the Bethell process creosote is used and in the Burnettizing zinc chlorid. The method of injecting the preservative into the timber is, in each case, practically the same. These two processes have long been accepted as standard, both in this country and in Europe, and they may serve as a basis for comparing the numerous adaptations which have been devised.

The timber to be treated is placed on iron trucks or "cylinder buggies" and run into huge horizontal cylinders, some of which are 8 or even 9 feet in diameter and more than 150 feet long. These are capable of withstanding high pressure, and their doors are so arranged that, after the timber is drawn in, they can be closed and hermetically sealed.

After the doors are closed live steam is admitted into the cylinder, and a pressure of about 20 pounds per square inch is maintained for several hours. In some cases the steam pressure is allowed to go considerably above 20 pounds, but this brings constant risk of injuring the strength of the timber. When the steam is at last blown out of the cylinder the vacuum pumps are started, and as much of the air and moisture as possible is exhausted from the cylinder and from the wood structure. This process also continues for several hours. Finally, after the completion of the vacuum period, the preservative is run into the cylinder at a temperature of about 160° F., and the pressure pumps are started and continued until the desired amount of preservative is forced into the wood. The surplus preservative is then blown back into the storage tanks, the timber is allowed to drip for a few minutes, and finally the cylinder doors are opened and the treated timber is withdrawn.

THE BOILING PROCESS.

This process is used principally on the Pacific coast, and for Douglas fir, an exceedingly difficult wood to treat. The timber, usually green, is placed in the treating cylinder, which is then filled with creosote heated to a temperature slightly above the boiling point of water. This hot bath is continued for from several hours to more than two days, depending upon the size and condition of the timber. During the bath much of the water in the sap is driven off, together with the volatilized light oils. These vapors are caught in a condenser, the water is decanted off, and the oil is run back into the receiving tank to be used over again. Finally, an oil pressure of 100 to 125 pounds is applied, and at the same time the temperature of the oil is allowed to fall, thus forcing the preservative into the timber.

It is a common practice in this country—and one which long experience in both Europe and America has proved unwise—to treat the timber before it has had time to dry out in the open air.

THE A. C. W. PROCESS.

In the A. C. W. process, after the timber has been subjected to the preliminary seasoning bath of live steam, and after a vacuum has been drawn, air is forced into the cylinder until a pressure of about 15 pounds is obtained. The creosote is then admitted, the air pressure being still maintained to prevent excessive or unequal absorption of the oil while the cylinder is being filled. The surplus air is allowed to escape through a pop valve at the top of the cylinder. When the cylinder is full of oil a pressure of 100 pounds or more is applied until the proper amount of the preservative has been driven into the timber. The oil is then run from the treating tank and an air pressure of 60 to 80 pounds applied. This is meant to drive the oil into the wood to a greater depth and to secure greater uniformity of treatment.

THE RÜPING PROCESS.

The Rüping process is one of the best-known "empty-cell" processes, and has been used largely in both Europe and America, but only with creosote. The preliminary processes of steaming and vacuum, as carried out in the Bethell treatment, are omitted entirely, and the wood is allowed to become air-dry before it is put into the treating cylinder. As soon as the doors are closed air is forced into the cylinder at a pressure of about 75 pounds, and so held until the spaces in the interior of the structure of the wood are filled with compressed air. Then, still maintaining this pressure, the oil is forced into the treating cylinder at a somewhat stronger pressure—say 80 to 85 pounds—and after the timber is all covered by the preservative the pressure is increased to about 225 pounds. This forces the oil to penetrate into the interior of the timber. Finally, the valves are opened, and the surplus oil is run back into the receiving tanks. This, of course, relieves the pressure around the timber, and the expansive force of the compressed air in the interior of the wood, sometimes strengthened by a vacuum drawn in the treating cylinder, forces out much of the oil, leaving merely a coating around the cell walls. A comparatively deep penetration, with a light absorption, is thus secured.

THE LOWRY PROCESS.

Like the Rüping method, the Lowry process aims to secure a good penetration with a comparatively small quantity of preservative. Also as in the Rüping, the timber is air-dried before treatment, but no compressed air is employed. During the seasoning process the evaporated water is replaced by air, and as soon as the cylinder doors are closed the oil is admitted and forced into the timber by pressure. This causes a compression of the air in the wood cells and intercellular spaces. Finally, the oil is run out of the cylinder and a strong, quick vacuum is drawn, and, as in the Rüping process, the sudden expansion of the air in the interior of the wood drives out the superfluous oil.

THE CREO-RESINATE PROCESS.

The creo-resinate process, as its name implies, consists in impregnating the timber with a mixture of creosote and resin, the proportion of creosote varying from 50 to 75 per cent. It has been used exclusively for the treatment of paving blocks. It further differs from the Bethell process in using dry heat instead of the steam bath before the vacuum.

THE WELLHOUSE PROCESS.

The solubility of zinc chlorid and its tendency to leach out of the treated timber on exposure to moisture has made it necessary to modify the treatments in a way to insure the permanency of the antiseptic salt in the wood. The Wellhouse process is one of these modifications, and it relies for its efficacy upon the tendency of glue and tannin, when combined, to form a leathery, waterproof substance, or "leatheroid." Accordingly, glue, in the form of a half per cent solution, is mixed with the zinc chlorid solution and forced into the timber, and a tannin solution is afterwards forced in as a separate treatment. The value of the process depends upon the formation of the "leatheroid" in the cell openings, to prevent the subsequent absorption of water and the leaching out of the salt.

THE ALLARDYCE PROCESS.

The chief drawback to the use of creosote is its cost, and to the use of zinc chlorid its tendency to leach out of timber that is exposed to moisture. Various attempts have been made to retain the good qualities of the two preservatives and at the same time to do away with their individual disadvantages. Thus, excellent results may be expected if the cheap and strongly antiseptic zinc chlorid can be

used for interior impregnation and its leaching out prevented by an outer zone of the insoluble creosote. The Allardyce process is one of the attempts to bring this about. It may be compared to the Wellhouse process, but with creosote as the plug instead of the glue-tannin "leatheroid." The timber is first treated with a 2 to 3 per cent solution of zinc chlorid, in the proportion of 12 pounds of the solution to each cubic foot of timber. The process is similar to that of Burnettizing. This is followed by a treatment with crosote, injecting about 3 pounds of the oil per cubic foot. The creosote, of course, remains chiefly on the outside, and is designed to protect the soluble chlorid in the interior.

THE CARD PROCESS.

This also is a creosote-zinc chlorid process. The preserving liquid is made up of from 15 to 20 per cent of creosote, and the remainder a 3 to 5 per cent solution of zinc chlorid. After a steam bath and a vacuum the preservative is admitted into the treating cylinder and pressure is applied. Since the creosote and the chlorid solution will not mix, and are of different specific gravities, they would soon separate if allowed to stand still. The timber on the top of the cylinder cars would be treated with zinc chlorid and no creosote, and the wood on the bottom with creosote but no zinc chlorid. To prevent this the solutions are kept in mechanical mixture by the use of a centrifugal pump attached to the treating cylinder. This pump is so connected with the cylinder as to draw the solution from the top, and to force it back again through perforated pipes running along the bottom of the cylinder. The process is really a modification of the Rütgers process, which employs an emulsion of the two preservatives, though difficulty is found in keeping the emulsion stable. This the mechanical device of the Card process aims to overcome.

THE NONPRESSURE PROCESSES.

The injection of the preservative by the nonpressure processes depends upon a different principle. The wood is first thoroughly seasoned, and much of the moisture in the cells and intercellular spaces is replaced by air. If the timber is peeled[a] after cutting and stacked in open piles the time required for seasoning can be greatly shortened. The seasoned timber, or that portion of it which is to be preserved, is immersed in a bath of a hot liquid in some con-

[a] It is important that the thin inner bark, as well as the heavier and thicker outer bark, should be carefully removed before treatment; as, especially in the case of pines and other coniferous woods, it often forms a barrier through which the preservative can not be forced, even under considerable pressure. After the timber is placed in ---vice the bark peels off or is broken, and the untreated wood beneath it is exposed -e attack of wood-destroying fungi.

venient containing vessel. This hot bath is continued for from one to five or six hours, depending upon the timber. During this part of the treatment the air and moisture in the wood expand and a portion of them pass off. At the end of the hot bath as quick a change as possible is made to a preservative at a lower temperature. This causes a contraction of the air and moisture remaining in the wood, and since a portion of them had been expelled a partial vacuum is created, which can be destroyed only by the entrance of the preservative. Thus atmospheric pressure[a] accomplishes what artificial pressure brings about in most of the commercial plants.

GREEN-TIMBER TREATMENTS.

If green timber must be treated it is necessary to prolong the hot bath until much of the moisture in the wood has been evaporated. Green wood, of course, contains comparatively little air to be expanded during the hot bath, and so the evaporation of the water can alone be depended upon to assist in producing the vacuum during the cold bath. The treatment of green timber is slow and unsatisfactory at best, and the prolonged hot bath is often expensive, not only through loss of time but by the added evaporation of the preservative, especially if creosote is used.

THE "OVEN" PROCESS.

The first hot bath in the nonpressure processes serves merely as a heating medium to expand the air and evaporate the moisture in the wood structure. Except in the case of very dry and porous woods, practically no penetration is secured until the cold bath, when the drop in temperature causes a contraction and condensation with a resulting vacuum. Much the same results can sometimes be secured by subjecting the timber to dry heat, or heating it in a kiln, as a substitute for the first hot bath, and then immersing it quickly in a cool bath of the preservative. Such a process is to be recommended only in special cases. Sometimes it is desired to penetrate the timber with a metal-corroding salt, when, of course, the usual equipment of iron tanks and steam coils can not be used. Mere seeping by immersion is often too slow to be satisfactory; but this difficulty can be relieved by heating the timber in an improvised kiln or "oven," and then immersing it quickly in the cool preservative contained in a wooden vat.

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[a] If a perfect vacuum were formed, which, of course, is impossible, the atmospheric pressure at sea level would amount to 14.7 pounds per square inch.

THE EMPTY-CELL NONPRESSURE PROCESSES.

It has been shown how, in the pressure processes, an empty-cell treatment is secured by means of force pumps, vacuum pumps, and compressed air. None of these devices are available in a nonpressure plant, where heat and atmospheric pressure alone can be employed. Even after an excellent full-cell treatment had been secured without artificial pressure there remained the problem of how to secure an equal penetration with a smaller quantity of the preservative; in other words, how to secure the greatest penetration with the least absorption. But here again the nonpressure principle proved successful, and it was found that with certain of the more porous woods an empty-cell treatment can be secured which compares favorably both in depth of penetration and amount of peservative with empty-cell treatments of the pressure plants. How this empty-cell nonpressure treatment is secured is shown in figure 3.

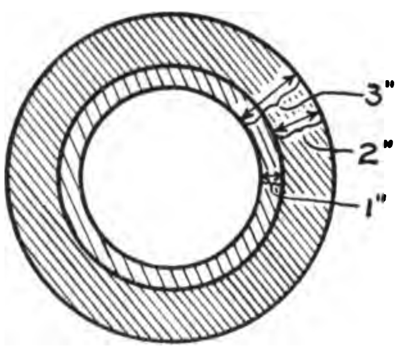
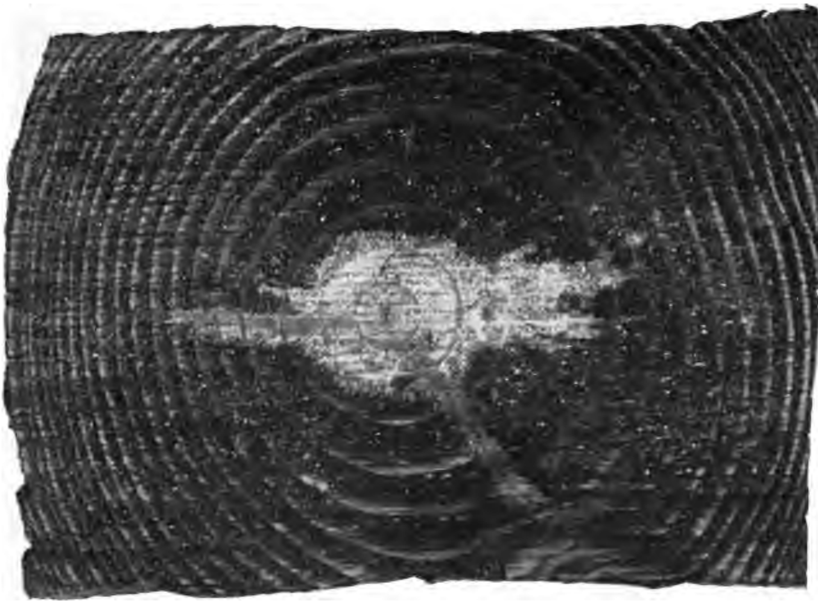


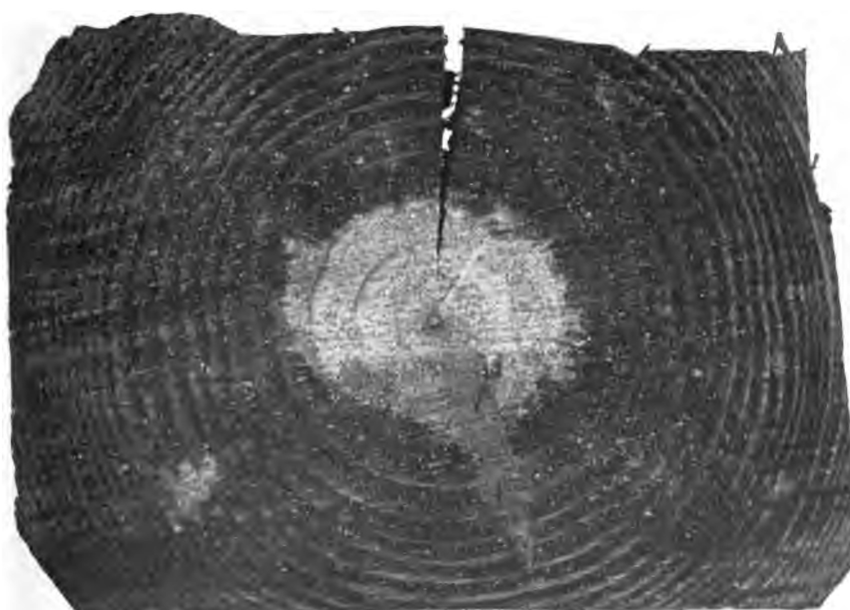
FIG. 3.—Diagram to illustrate how an empty-cell nonpressure treatment is secured.

In the absence of conclusive data, the following explanations can be accepted only as reasonable hypotheses:

Suppose that the first hot bath partially expelled the air and moisture from a stick of timber to a depth of 3 inches from the surface. When the cold bath is applied it is, of course, nearest the surface that the drop in temperature first takes place, and so it is in the outer band of the wood that the vacuum is first formed. This causes an immediate inrush of the preservative, which thoroughly saturates the cellular and intercellular spaces in that portion of the stick. Now suppose that the stick is withdrawn from the cold bath as soon as the preservative has penetrated only 2 inches, instead of the full 3 inches which was effected by the hot bath. As the temperature in the third inch continues to drop, even though the cold bath has been discontinued, a vacuum is formed, to destroy which the superfluous oil from the saturated outer 2-inch zone is forced into the inner 1-inch zone. Thus a penetration of 3 inches is secured with no more preservative than is required to saturate 2 inches. (See Pl. III.)

Similar results can sometimes be approached by a second hot bath; that is, a treatment consisting of, first, the hot bath, second, the cold bath, and finally, another bath in the hot oil. At the end of the cold bath the oil has penetrated the timber to a certain depth. Upon reheating, the oil acts as a better conductor of heat than the wood fiber, and so the interior of the stick is heated more quickly





SECTIONS OF LOBLOLLY PINE TIES TREATED BY THE EMPTY CELL NONPRESSURE PROCESS.

and to a higher temperature than was possible during the first hot bath. This causes a second expansion and expulsion of air and moisture, and when the timber is finally cooled in the open air some of the free oil in the outer portion of the stick is driven into the interior.

THE LOW-PRESSURE PROCESS.

This process has been developed by the Forest Service in the endeavor to combine the pressure and nonpressure processes so as to secure the advantages of both. The seasoned timber is first subjected to a hot bath, as in the true nonpressure treatment, and the desired expansion and partial expulsion of the air and moisture is secured. Then the cold bath is applied, but instead of depending solely upon atmospheric pressure to drive the preservative into the wood, a moderate artificial pressure is also applied. This often means a decided reduction in the time required for the treatment, a greater absorption of the preservative, and a deeper and more uniform penetration. A nonpressure plant with a cylinder 6 feet in diameter, constructed of three-eighths-inch steel, is fully capable of withstanding a pressure of 70 pounds per square inch, and the same pump which conveys the preservative from the underground receiving tank to the storage tanks can be used to apply the pressure. Practically the only thing necessary to equip a nonpressure cylindrical plant to stand moderate or low pressures is to increase the strength of the attachments of the doors to the cylinder. Of course the low-pressure process can not be used in an open-tank plant.

The field of the nonpressure and low-pressure processes is by no means as broad as that of the pressure processes. They are not adapted to the treatment of the nonporous woods, or to great quantities of timber where the time of treatment is an important factor. On the other hand, they offer a cheap, simple, and efficient treatment for comparatively small quantities of the easily impregnated woods. They will not come into strong competition with the high-pressure systems, for although the boundaries of their fields may occasionally overlap, the nonpressure and low-pressure plants will be used chiefly for the treatment of timber which otherwise would remain untreated.

SUPERFICIAL TREATMENTS.

THE BRUSH METHOD.

A less efficient but cheaper treatment can be secured by painting the surface of the timber with at least two coats of hot creosote or some similar preservative. The liquid may be applied with an ordinary paint brush, but care should be taken to fill thoroughly with the preservative all checks, knot holes, and similar defects. The liquid can penetrate only a very short distance into the wood, but as long as there remains an unbroken antiseptic zone around the surface the spores of the wood-destroying fungi can not enter. It is

especially important in this method that the timber should be thoroughly air dry before treatment, otherwise the evaporation of water from the interior of the stick will cause checks, and so expose the unprotected wood to fungous attack.

This process finds its principal use where the amount of timber to be treated is too small to justify the erection of even a small treating plant; where the land is so rugged, as in the building of mountain telephone lines, that it is impracticable to transport the timber for even a short distance; or where it is necessary to restrict the cost of the treatment to the least possible figure. Its disadvantage is in the liability of the thin coating of the treated wood to be broken or scurfed off, thus permitting the spores of the wood-destroying fungi to enter and destroy the interior of the stick.

DIPPING.

Even where merely a superficial coating of the preservative is desired, the brush treatment is often more expensive than is "dipping" the timber directly in an open vat of the liquid. It is much simpler, for instance, to pass a hundred ties through a shallow vat of the preservative on chain conveyors than to paint their surfaces with a brush. Dipping is often not only more economical of labor, but it also more thoroughly fills the checks, knot holes, and other defects which are so apt to be neglected in applying a brush coating. The time the timber is allowed to remain in the preservative varies from a very short immersion to fifteen or twenty minutes, or even longer, depending principally upon the moisture content of the timber (whether green or seasoned), the readiness with which it absorbs the preservative, and the desired limit of expense.

The word "dipping" is sometimes used synonymously with "open-tank," or "nonpressure" processes. This is incorrect and misleading. In the latter processes the absorption of the preservative is secured by the combined effects of a hot bath, a cold bath, and the resulting vacuum; and the penetration usually varies from one-half inch to several inches. By "dipping" is generally understood a simple short immersion in the preservative, without variation in temperature, and resulting in merely a thin superficial penetration.

THE EFFECT OF TREATMENT ON THE STRENGTH OF TIMBER.

The question is frequently asked whether the strength of timber is impaired by the preservative processes in common use. No general answer to this can be given, since it depends altogether upon the character and strength of the preservative and the care with which it is injected. It is probable that creosote does not penetrate the wood fibers, but merely forms an external coating around them; hence in itself it can not appreciably affect the strength of the timber. In general the ultimate strength of treated

timber depends, first, upon the percentage of moisture remaining in the wood; and, second, upon whether the wood has been subjected to injuriously high temperatures during the preliminary processes of steaming and vacuum, if these processes are employed. The degree of heat which can be applied without risk of serious injury depends upon the duration of the temperature, the moisture content and quality of the wood, and the pressure to which it is subjected.[a]

If proper care is used in the treatment of the timber all danger of injury from excessive temperatures can be avoided. The amount of moisture remaining in the wood is, therefore, a point of greater importance. As the moisture in a piece of wood is reduced by drying the strength of the wood increases, and as moisture is subsequently reabsorbed the strength up to a certain limit is again reduced. Creosote retards both the absorption and evaporation of water; hence its presence in thoroughly seasoned wood exposed to humid conditions tends to conserve its strength; whereas, on the other hand, if it is applied to green wood, the strengthening action of water evaporation is retarded. Some processes tend to increase the moisture content of the wood and others to diminish it. Therefore, whether the strength of timber is increased during creosoting depends chiefly upon the process employed.[b]

The effect which live steam at safe temperatures has upon the moisture content of wood is now being made the subject of a special study. It is safe to say, however, that during steaming the amount of moisture in air-dry timber is increased, with a consequent decrease in strength, and that the succeeding vacuum fails to remove all of the added moisture before the introduction of the preservative. With many kinds of air-dry timber, however, the steaming can be dispensed with altogether, and this is done in many commercial plants. Whether it can be omitted with all kinds of wood is not yet certain.

These considerations, of course, do not apply to the nonpressure methods, or to similar processes where the timber is immersed directly in the hot preservative, without the preliminary steaming and vacuum. Immersion in hot oil tends to evaporate some of the moisture in the wood and so to increase its strength.

Zinc chlorid and the other preservatives which are in water solution have a wholly different effect. Unless the wood structure is already filled with moisture to the point of saturation, more water is injected into it with the preservative, with the result, if the wood is partially seasoned, of decreasing its strength. The original

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[a] Detailed discussions of these points will be found in Forest Service Circulars Nos. 39 and 108.

[b] A discussion of the moisture content of creosoted wood may be found in Forest Service Circular 134, The Estimation of Moisture in Creosoted Wood.

strength may be regained, however, by seasoning the timber after treatment. If the zinc chlorid is injected into the timber in too concentrated a solution, it may cause a chemical dissolution of portions of the wood fiber, with the result of permanently decreasing the strength of the timber. But for the solutions in common use this danger need not be considered.

THE NATIONAL VALUE OF WOOD PRESERVATION.

Not only does the preservative treatment of timber bring about a direct saving to the individual timber user, but the general adoption of such measures means a very great saving to the timber resources of the nation as a whole. At the present rate of consumption the exhaustion of the supply of the better class of structural timbers in the United States is a thing of the very near future. Even the cost of fence posts is becoming an ever-increasing burden upon the farmer and stockman. The principal agents which destroy structural timber are decay, fire, insects, marine borers, and mechanical abrasion. Of these, the first is far more important than all the others put together. In the following table an attempt has been made to summarize the annual destruction of timber in the United States due to these five agencies. It is well known that the quality of timber in general use is deteriorating each year, so much so in many respects as to cause a complete revision in the specifications for grading it. This is due chiefly to the partial exhaustion of the better grades, which has forced the utilization of the poorer qualities. This deterioration in quality naturally results in a decreased length of life, which in turn compels a larger annual cut of timber. Hence the amounts given in Table 1 will increase year by year in proportion to the decrease in quality.

TABLE 1.—*Estimated annual destruction of cut timber in the United States.*[a]

[M feet B. M.]

Class.	Total destroyed annually requiring replacement.	Destroyed by—									
		Decay.		Fire.		Insects.		Marine borers.		Mechanical abrasion.	
		Amount.	P.ct.	Amount.	P.ct.	Amount.	P.ct.	Amount.	P.ct.	Amount.	P.ct.
Ties	3,300,000	[b]2,871,000	87			16,500	½			412,500	12½
Poles	147,720	140,334	95			5,908	4			1,477	1
Posts	3,000,000	2,700,000	90	165,000	5½	120,000	4			15,000	½
Mine props	402,000	281,400	70	2,010	½	38,190	9½			80,400	20
Piles	191,520	9,576	5					181,944	95		
Shingles	1,100	1,045	95	55	5						
Lumber	2,625,000	1,863,750	71	131,250	5	315,000	12	52,500	2	262,500	10
Total	9,667,340	7,867,105	81	298,315	3	495,599	5	234,444	3	771,877	8

[a] The annual replacements of each class are found by dividing the total amount of timber in use by the estimated average life of the untreated timber. The quantities destroyed by decay, fire, etc., are of necessity only approximations.

[b] This figure includes destruction due to fire as well as to decay.

It is thus seen that the enormous amount of nearly 10 billion board feet of structural timber is destroyed each year in the United States; and of this amount nearly 8 billion, or 81 per cent, is due to decay. That much of this timber can be saved by proper methods can readily be shown.

TIES.

For instance, it is estimated that the average life of all untreated ties used in the United States is seven years; and seventeen years, if treated. Assuming the total number in use as 700,000,000, if none were treated the annual replacement would amount to one-seventh of 700,000,000, or 100,000,000. Assuming them all to be properly treated, the annual replacement would amount to approximately one-seventeenth of 700,000,000, or 41,200,000. Hence the decrease in the annual cut which would ensue from a proper preservative treatment of all railroad ties annually used would amount to approximately 58,800,000 ties, or an equivalent of nearly 2 billion feet board measure.

POLES.

It is estimated that the average increased life which would result from a proper preservative treatment of all poles used in this country is approximately 10.25 years. It is also estimated that the average life of all the poles used, if untreated, would be approximately thirteen years. Assuming that there are 32,000,000 poles in use, if none were treated the annual replacement would amount to one-thirteenth of 32,000,000, or 2,462,000 poles. Again, assuming that they were all properly treated, the annual replacements would amount approximately to 32,000,000 divided by 23.25, or about 1,380,000. Therefore the decrease in the annual cut which would result from a proper preservative treatment of all poles would be approximately 1,082,000 poles, or an equivalent of 64,920,000 feet board measure. In obtaining the above figures no allowance was made for the fact that in general practice the greater percentage of treated poles are of the so-called "inferior" species. These kinds of timber, when properly treated, will have their natural life increased by more than the general average of 10.25 years. (See Pl. II.)

PILES.

The average life of all piles used in the United States in an untreated condition is three and one-half years. It is estimated that if all were treated the average life would be twenty-one and one-half years, or, in other words, the increased life due to a proper treatment of all piles would amount to approximately eighteen years. Assuming that there are approximately 4,000,000 piles in use, the annual

replacement, if none were treated, would be 4,000,000 divided by 3½, or 1,140,000 piles. If they were all properly treated, the annual replacement would be 4,000,000 divided by 21½, or only 190,000 piles. Hence the decrease in the annual cut which would result from the proper preservative treatment of all piles approximates 950,000 piles, or an equivalent of 159,600,000 feet board measure. In the above estimates the average pile is considered to be 40 feet long and to contain 168 feet board measure.

POSTS.

The average life of all of the fence posts used in the United States, if untreated, is estimated at approximately eight years. With a proper preservative treatment this life may be increased fourteen years, giving a total service of twenty-two years from the treated posts. Estimating the total number of posts in use as 4 billion, equivalent to about 24 billion board feet, the annual replacement, if none were treated, would be one-eighth of 4 billion, or 500 million posts. If properly treated, the replacement would amount to only one twenty-second of 4 billion, or 180 million posts. Thus, by a proper preservative treatment, there would result an annual saving of approximately 320 million posts, or an equivalent of 1,900,000,000 feet board measure.

MINE PROPS.

The estimated life of an untreated mine prop is approximately three years. With a proper preservative treatment this life may be increased by approximately ten years, giving a total life for the treated props of thirteen years. All of the mine props, both round and square, in use in the United States, contain approximately 500 million cubic feet. About 40 per cent of this quantity, or 200 million cubic feet, can be advantageously treated. If no preservative methods were used the annual replacement of this 40 per cent would amount to one-third of 200 million, or approximately 67 million cubic feet of timber. If they were all given a proper preservative treatment the annual replacement would be reduced to one-thirteenth of 200 million, or approximately 15,300,000 cubic feet. Hence, by a proper preservative treatment of all mine timbers which can be treated advantageously, an annual saving would result of approximately 51,700,000 cubic feet, equivalent to 310,200,000 feet, board measure, or more than half of the present annual cut. (See Pl. I, fig. 2.)

SHINGLES.

The average life of all shingles used in the United States, if untreated, is estimated at approximately eighteen years. If all were treated it is probable that they would last thirty-two years, or an increase of fourteen years, due to the preservative treatment. Assuming that there are 20 million feet board measure of lumber in use as shingles at the present time, if all were untreated the annual replacement would amount to approximately one-eighteenth of 20 million, or 1,100,000 feet board measure. If they were all treated the annual replacement would amount to only one thirty-second of 20 million, or 625,000 feet board measure. A proper treatment would therefore result in a saving of approximately 475,000 feet of lumber board measure. These estimates for shingles, however, are by no means as accurate as those for other classes of timber, and therefore reference to them has been omitted from Table 3.

LUMBER.

The average life of all lumber used in the United States which is subject to decay is about eight years, and if properly treated it would be about twenty years—an increased life of twelve years. If we assume that of all of the lumber used annually in the United States 21 billion feet is subject to decay and can be treated with profit, the annual replacement, if none were treated, would amount to one-eighth of 21 billion, or 2,625,000,000 feet board measure. If all of this were properly treated the replacement would amount to only one-twentieth of 21 billion feet, or 1,050,000,000 feet board measure. Hence the decrease in the annual cut which would result from the proper preservative treatment of all lumber subject to decay would approximate 1,575,000 feet board measure.

These estimates are summarized in Table 2.

TABLE 2.—*Estimated reduction in annual cut which would ensue from a proper preservative treatment of all timber from decay.*

Class.	Estimated average life in years.		Estimated annual replacements, all species.		Estimated saving in annual cut due to treatment.	Total annual saving, equivalent board measure.
	Untreated.	Treated.	Untreated.	Treated.		
			Number.	*Number.*	*Number.*	*M feet.*
Ties	7	17	100,000,000	41,200,000	58,800,000	1,940,000
Poles	13	23½	2,462,000	1,380,000	1,082,000	64,920
Posts	8	22	500,000,000	180,000,000	320,000,000	1,900,000
Piles	3½	21½	1,140,000	190,000	950,000	159,600
Mine props	3	13	[a] 67,000,000	[a] 15,300,000	[a] 51,700,000	310,200
Shingles	18	32	[b] 1,100,000	[b] 625,000	[b] 475,000	475
Lumber	8	20	[c] 2,625,000	[c] 1,050,000	[c] 1,575,000	1,575,000
Total						5,950,195

[a] Cubic feet. [b] Feet B. M. [c] M feet B. M.

Table 1 shows that nearly 10 billion feet board measure of structural timber are destroyed each year in the United States. Table 2 shows that, if all the timber were treated which it is practicable to treat and which could be treated at a profit, nearly 6 billion feet board measure, or over 60 per cent, could be saved. This saving would represent the annual growth on 20 million acres of well-stocked timber land.

THE SAVING IN DOLLARS AND CENTS.

Wood preservation, while important in its broad national aspect, is also of direct personal importance to every user of timber which is exposed to decay or insect attack; for by lessening the cost of maintaining his fences, his telephone line, or his track, it means a direct saving in dollars and cents. No process to preserve timber will come into use unless it is certain that the outlay for the treatment will be more than offset by the longer service of the treated timber. It is difficult to give a specific example, applicable to all parts of the country; but the following estimates represent the most reliable information which the Forest Service has been able to obtain, and while not absolutely accurate, it is believed they are conservative and can safely be relied upon to give a general idea of the saving that may be expected from a proper preservative treatment. More accurate figures for any particular locality and kind of timber can readily be obtained by the same means.

The average cost of an untreated fence post in the United States is 10 cents. The value of the labor necessary to place it in the line is also 10 cents, making the set post cost 20 cents. Its average length of life is eight years. Compounding interest at 6 per cent, the annual charge for such a post is 3.2 cents; that is, it costs 3.2 cents a year to keep such a post in service. If given a preservative treatment, at a cost of 12 cents, the life of the post is increased to twenty-two years. The total cost of such a post, set, is then 32 cents, which, compounded at the same rate, gives an annual charge of 2.6 cents. Although the yearly saving of six-tenths of a cent per post may seem small, yet it is estimated that there are 4 billion posts in the fence lines in the United States, and if all these were treated there would be a saving of about 24 million dollars per year. Moreover, the case cited above is the average for the entire country, timbered regions as well as prairie, and in many localities a much greater saving can be secured. Thus in the South, a thoroughly treated scrub or old-field pine post is more than the equal of an untreated red cedar; and in the middle western and Rocky Mountain States cottonwood, willow, or lodgepole pine can, by treatment, be made to give much better service than the expensive cedar shipped from the extreme Northwest.

SPRUCE PILE DESTROYED IN THREE YEARS BY MARINE BORERS IN THE HARBOR OF KLAWOCK, ALASKA.

Or take the case of telephone poles: The average cost of a pole set in the line is $7, and it lasts thirteen years. The annual charge, compounding interest at 6 per cent, amounts to 78 cents. In other words, the average pole in the lines of the United States each year costs its owner 78 cents. This corresponds to a capital of $14.67 invested at 6 per cent, or for a mile of 40 poles, to about $587. Again, assuming that the average treatment costs $1.50, the first cost of the pole set in the ground is $8.50. The average life which may reasonably be expected from the treated poles is about twenty-three years, instead of the thirteen years when untreated. Thus, the annual charge in the treated pole, at the same rate of compound interest, is only 69 cents, which corresponds to an investment of $11.50, or $460 per mile as compared with $587 per mile in the other case. Thus, during the life of the treated pole a yearly saving of the interest on $127 will be effected for every mile of line. As there are about 32 million poles in use in the United States, an annual saving of about $2,880,000 would ensue from the proper treatment of them all. (See Pl. II.)

In the following table is a summary of the estimated financial saving per annum which would result from a proper preservative treatment of all kinds of structural timber which can be treated with profit:

TABLE 3.—*Estimated annual financial saving by proper preservative treatment.*

Class.	Initial cost.[a]			Cost of treatment.	Years life.		Annual charge.		Annual saving.	Quantity in use.	Total saving.
	Material.	Placement.	Total.		Untreated.	Treated.	Untreated.	Treated.			
Ties	$0.470	$0.20	$0.670	$0.35	7	17	$0.120	$0.097	$0.023	700,000,000	$16,100,000
Poles	4.000	3.00	7.000	1.50	13	23¼	.780	.690	.090	32,000,000	2,880,000
Posts	.100	.10	.200	.12	8	22	.032	.026	.006	4,000,000,000	24,000,000
Piling[b]	.100	.05	.150	.25	3½	21½	.050	.034	.016	4,000,000	1,800,000
Mine props[b]	.045	.23	.275	.11	3	13	.100	.040	.060	200,000,000	12,000,000
Lumber[c]	16.500	2.00	18.500	10.00	8	20	2.980	2.480	.500	[d]30,000,000	15,000,000
Total											71,780,000

[a] The initial cost is taken at the point of purchase, no allowance being made for freight charges.
[b] Charges per cubic foot.
[c] Charges per M feet B. M.
[d] Refers only to that adapted to treatment.

It might be said that it is not positively proved that the treated timber will last as long as the estimates, and that it will be necessary to wait until the timber is actually removed before the length of its service can be ascertained.

There is no reasonable ground for such an argument. There is abundant evidence to show the life of properly treated wood. Even in this country there are many examples of poles and other timbers